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A decision-making model for the analysis of offshore wind farm projects under climate uncertainties: A case study of South Korea

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ABSTRACT

Wind power supplies clean energy, but it is vulnerable to climate change. As the impacts of climate change increase, economic assessment methods of wind power projects are required to capture climate uncertainties. The study proposes a decision-making model to analyze the economic feasibility of offshore wind farm projects considering the impacts of climate change using real options analysis (ROA). The model can consider project volatility using the wind speed projected from climate scenarios that affect wind power production. A case study of an offshore wind farm in South Korea was conducted to confirm the validity of the proposed model. The case study proved that the managerial flexibility provided by the proposed real options effectively reduces risks and increases the long-term profitability of offshore wind farm projects.

1. Introduction

Wind power produces renewable electricity using wind resources [1]. Wind resources are abundant and evenly distributed in nature, and they are not depleted, unlike oil and coal [2]. Wind power is the first renewable energy source to have achieved grid parity [3]. Wind power facilities with generation capacity of 433 GW (gigawatts) were installed by 2015, accounting for 3.7% of the world's electricity consumption [4]. Globally, US$ 109.6 billion was invested in newly installed wind power in 2015, accounting for 38.3% of the total investment in renewable energy in 2015 [4]. Wind power is divided into onshore and offshore wind power based on the location of the facility. The capacity of offshore wind power facilities installed in 2015 was approximately double the capacity of those installed in 2014 [4]. The construction cost of offshore wind power, which was high compared to that of onshore wind power, has been drastically lowered because of the development of new technology [5].

Renewable energy sources, such as offshore winds, are generally associated with high uncertainty. As climate uncertainty increases, it becomes increasingly difficult to predict the amount of wind power production. In order to assess the economic feasibility of wind power project, it is very important to estimate the production amount. The discounted cash flow (DCF) method has been used as a major tool to understand the economic feasibility of energy projects. However, in this method, it is difficult to reflect the managerial flexibility that can be exercised considering the uncertainties in the business environment [6]. This study aimed to develop a model that can analyze the economic feasibility of offshore wind farm projects considering future climate change impacts. Because the impacts of climate change have increased worldwide, this study should not rely on past climate information [7]. The proposed model uses climate scenarios to quantify climate uncertainties and estimate the profit from a given investment. Using the proposed model, investors can decide whether they want to expand their investment, continue at the same level, or abandon it depending on the specific climate situation using ROA. Decision makers can establish the most appropriate strategy for an offshore wind farm project considering climate change using the proposed model. The remainder of this paper is organized as follows. Section 2 presents a review of past related studies on the impacts of climate change on wind power projects, methodologies for investment decisions, and ROA. Section 3 presents the proposed model methodology, while Section 4 shows how the model was validated through a case study of a 99.2 MW offshore wind farm in South Korea. Section 5 discusses the results of the case study and derives the implications. Finally, Section 6 summarizes the research and presents conclusions, including the contributions of this study.

2. Literature review

Wind power production is heavily influenced by climate factors [8].

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An increase in the uncertainty associated with the supply of wind resources makes it difficult to predict wind power production. Depending on the region, climate change causes changes in annual wind volume and affects wind quality [9]. Based on the climate scenarios, climate change alters wind density and speed [10]. Wind power production is mainly determined by wind speed [11]. Fluctuations in wind speed make it difficult to determine the investment feasibility of projects.

Efforts have been made to accurately estimate the feasibility of wind farms in different regions of the world. Satir et al. [12] proposed a methodology to determine the feasibility of a wind energy project in Turkey based on the historical data of the Aegean Sea. Barroso and Iniesta [13] estimated the annual electricity production of a wind power project in Germany using the past monthly data of wind speed. Pryor and Barthelmie [14] claimed that wind energy would be a sustainable source of renewable energy even with climate change in Northern Europe. Using three years of wind speed data, Shoaib et al. [15] showed that a wind farm in Baburband, Pakistan, was economically feasible at 80-m mast height.

Recently, climate scenarios have been used for studies on the economic analysis of wind power projects. Davy et al. [10] predicted wind resources by estimating future wind speeds in Europe to analyze the economics of wind energy projects under regional climate scenarios. Koletsis et al. [11] estimated the potential production of offshore wind power in the Mediterranean Sea and the Black Sea using regional climate scenarios. Ruffato-Ferreira et al. [16] found that the use of wind speed information from climate scenarios facilitated the prediction of wind power production in a Brazilian case study.

In general, economic analysis for investment decisions in the wind power business is performed using a traditional economic analysis method called DCF, which is represented by the net present value (NPV) and the internal rate of return (IRR) [17]. This method is the most widely used economic analysis tool for various investment projects but not for projects with high volatility and uncertainty [6]. In particular, the traditional methods are inappropriate for evaluating renewable energy projects that are highly affected by climate uncertainty [18]. ROA, which can consider climate uncertainty, can be a better tool for the feasibility analysis of renewable energy investments [19,20]. Martinez-Cesena and Mutale [21] argued that the uncertainty of wind power projects could be assessed using ROA.

This study provides a decision-making model using ROA. Option values are calculated by a binomial lattice approach. Two option pricing approaches are widely employed: (1) the Black–Scholes approach and (2) the binomial lattice approach. The Black–Scholes approach analyzes the option values using a partial differential equation with the assumption of European options that are only exercised at the proposed time of the project period [22]. However, the ROA in infrastructure projects has mostly the American options that can be excised at any time during the project period. The binomial lattice approach is mostly used for real options pricing, as it allows easy calculation and visual interpretation, applicability of any type of option, and decision-making at any time during the project period [23]. The binomial lattice approach assumes that an underlying asset rises or falls and can be applicable under various cases, so it can be applied to both European and American options [24]. The case study of an offshore wind farm project has the American option. Thus, it is also reasonable to use the binomial lattice approach for the ROA of the case study.

ROA has been used for understanding the economic feasibility of a single wind power project. Loncar et al. [3] applied a compound option model to a wind power project in Serbia. Abadie and Chamorro [25] developed an ROA model for investment in a wind farm in the UK considering future electricity markets. Lee [26] proved the effectiveness of the ROA in the case of a Taiwan-based wind power project using the Black–Scholes option pricing model. Considering wind power generation costs, government subsidies, and volatility in power production, Reuter et al. [27] presented an ROA model for wind power investment with hydro-pumping storage in Germany and Norway. Kim et al. [28] proposed a compound options model to evaluate a wind power project considering the optimal investment time under uncertain energy markets in South Korea.

The effects of wind energy policies were studied to promote the investment in wind power projects. Venetsanos et al. [29] developed an ROA framework for supporting investment decisions in wind energy projects after the deregulation of the Greek electricity market. Yang et al. [30] proposed a Clean Development Mechanism policy based on the ROA of wind power projects in China. Boomsma et al. [31] used ROA to suggest a government subsidy policy in Norway for encouraging wind power projects. Kitzing et al. [32] developed an ROA model to determine the size and timing of a wind power project considering different support policies in Denmark.

Previous studies have widened the application of ROA to wind power projects. However, there is a lack of applicable methodologies that consider the impacts of climate change on wind power projects. Thus, this study proposes an ROA model applicable to wind power projects. In order to minimize the impacts of climate change, this study applies real options to wind farm projects using future climate scenarios.

3. Methods

3.1. Decision-making model for offshore wind farms

The cost of constructing an onshore wind power plant is lower than that of an offshore plant, but onshore plants have the disadvantages of noise generation and unstable wind direction and speed [33]. Offshore wind power plants generate more stable wind power than onshore wind power plants, but their installation costs are high and connecting such plants to the electricity grid is expensive [33]. To lower cost, economies of scale with offshore wind power must be achieved. Thus, it would be desirable to have, for example, an expansion option so that the project could be expanded later if the business environment is positive. This study proposes a decision-making model for investment in offshore wind farm projects using real options. With this model, investors can retain and exercise such options to avoid risks arising from uncertainties in long-term projects and preserve or enhance the project value [34]. The model proposed herein comprises three steps: 1) analyzing the impacts of climate change on offshore wind power projects, 2) forecasting wind energy production based on climate scenarios, and 3) calculating the option value and determining investment strategies (Fig. 1). A detailed description of each step is given in the next section.

3.2. Impacts of climate change on energy production

Climate scenarios are often used to assess the economic feasibility of projects that consider the impacts of climate factors [20]. This study uses the Representative Concentration Pathways (RCPs) climate scenarios published by the Intergovernmental Panel on Climate Change (IPCC) in 2014 [35]. The RCP scenarios simulate the degree of climate change in the future based on the changes in CO_2 emissions and comprise four different scenarios (RCP8.5/6.0/4.5/2.6). RCP2.6 is a climate change scenario that remains at pre-industrial global warming levels, RCP8.5 is a climate scenario that would occur if no efforts are made to reduce greenhouse emissions, and RCP4.5 and RCP6.0 are intermediate climate scenarios [35]. Future wind power production is estimated using time-series wind speed data simulated using both RCP2.6 and RCP8.5. The impact of climate change is the highest under RCP8.5 and the lowest under RCP2.6.

Offshore wind power projects that use wind resources to produce energy are vulnerable to climate change impacts. Wind speed is the most important climate uncertainty factor that determines wind power production [3]. The amount of wind power production P_{wind} is determined using Eq. (1) [11,17]:

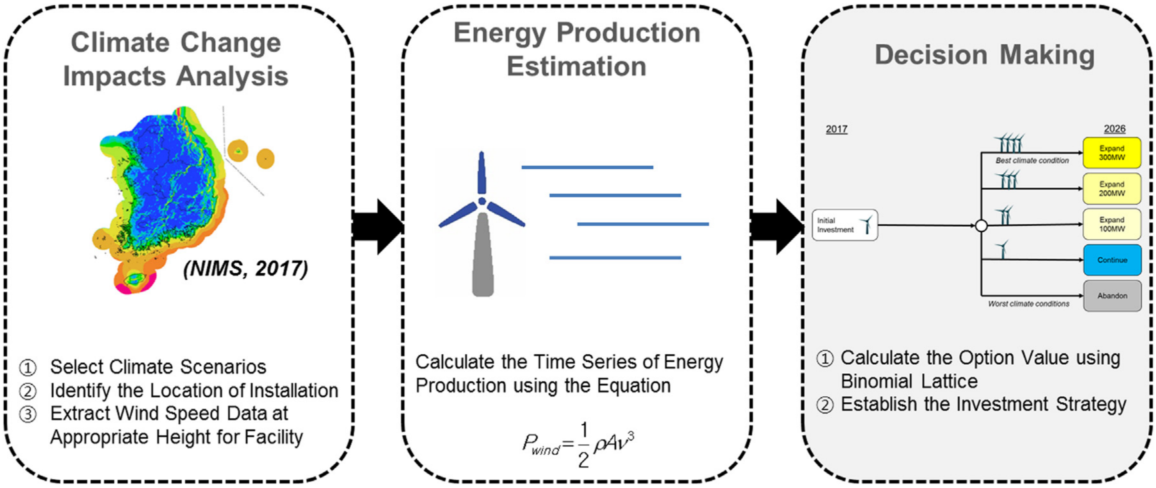

Fig. 1. Decision-making model for offshore wind farm.

$$P_{wind} = \frac{1}{2}\rho A v^3, \tag{1}$$

where ρ is the air density (kg/m^3), A is the rotational cross-sectional area of a blade (m^2), and v is the wind speed (m/s). The magnitude of the wind speed, a climatic factor governing the project area, determines the energy produced by a wind power project. Wind power production is proportional to the cube of wind speed. If other conditions are the same, the decision maker should choose the installation location with the best wind speed to maximize the amount of wind power produced. Predicting future wind speed is the most important issue in making investment decision on long-term wind power project.

3.3. ROA

An offshore wind farm can be economically viable if economies of scale are achieved [36]. Herein, the expansion option is applied to an offshore wind farm project to achieve the economies of scale. Expansion options are used to maximize profit by expanding the project [26]. However, if the business environment worsens and future prospects of profit are dim, decision makers no longer need to invest. Fig. 2 shows various cases of the application of options to a wind farm project under climate change. If an option is planned to be executed in year N, the investor can make a decision about whether to expand wind power facilities considering the information about the impacts of climate that has been accumulated by that time. The scale of facility expansion is determined based on the predicted wind power production. However, in the worst of climate scenarios, existing facilities may have to be disposed of or sold. Otherwise, existing facilities will continue to be maintained in their current state. Thus, considering the impacts of climate change, investors can choose among expansion, continuation, and abandonment.

Considering the impact of future climate change as well as other factors affecting the project revenue, the volatility in revenue is estimated to quantify the uncertainty of an investment. Mun [37] proposed a logarithmic cash flow returns method using future cash flows and determined the volatility σ using Eq. (2):

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}, \tag{2}$$

where n is the number of cash flow returns, x_i is the individual cash-flow return (US$) in year i, and $\bar{x}$ is the average of x_i. Copeland and Antikarov [38] argued that the current value of the most likely cash flow is the unbiased underlying asset value S_0. The option values are calculated using a binomial lattice (Fig. 3). An option value is obtained by the formation of the up movement $u = e^{\sigma\sqrt{\Delta t}}$, down movement $d = \frac{1}{u}$, and risk-neutral probability $q = \frac{(e^{rt} - d)}{u - d}$, which are estimated using Eq. (3) [39]:

$$OV = e^{-rt}[qOV_u + (1-q)OV_d], \tag{3}$$

where Δt is the time-step increment, r is the risk-free interest rate, and OV_u and OV_d are the option values coupled with the up and down movements, respectively. The option value in each node in the binomial

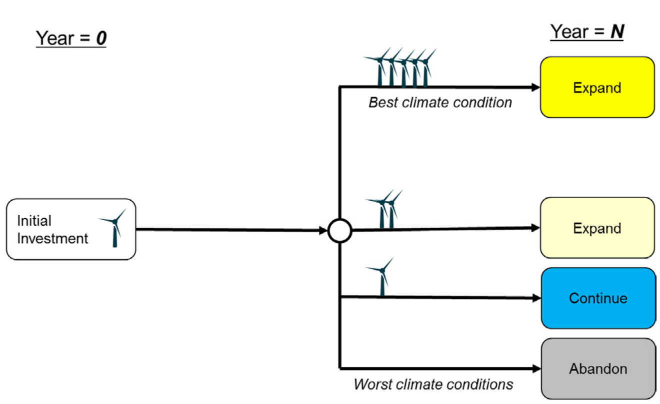

Fig. 2. A wind power project with options.

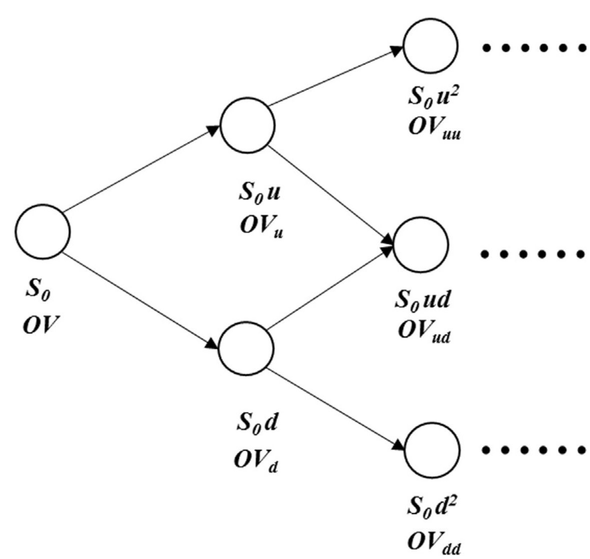

Fig. 3. Binomial lattice.

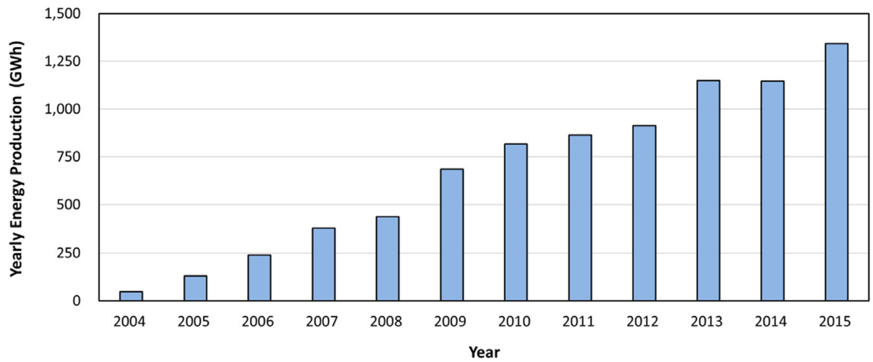

Fig. 4. Yearly production of wind power in South Korea [41].

lattice displays the maximum value among the values of expansion, continuation, and abandonment options.

4. Case study: Application of the decision-making model to an offshore wind farm in South Korea

4.1. Case description

The South Korean government is attempting to increase the proportion of renewable energy, which stood at 4.9% of the total energy generated in 2015, to 11% by 2030 [40]. As of 2015, wind power accounted for 11.1% of the renewable energy in the country, with an installed capacity of 852 MW [41]. The installed capacity increased by 32.1% compared to the previous year, and the total annual production of wind power stood at 1342 GWh in 2015 [41]. Fig. 4 shows the annual production of wind power between 2004 and 2015 [41].

The Saemangeum development project is a national project to build a global free-trade zone and agricultural land along the world's longest sea wall (33.9 km) connecting Gunsan-Si and Buan-Gun, which the South Korean government has been pursuing since 1991 to reclaim land (291 km^2) and develop artificial lakes (118 km^2) [42,43]. The Saemangeum offshore wind farm project was originally planned in Jeollabuk-Do as a pilot wind farm as the basis for cultivating South Korea's wind power industry in 2009. The project commenced in 2017, with a capacity of 99.2 MW and an investment of approximately US$ 400 million [44]. If the project is successfully completed, it will be the largest offshore wind farm in South Korea and will supply electricity to the Saemangeum area. Fig. 5 shows the project location.

From commencement in 2017, the construction period is two years, and the operation period is assumed to be 20 years. The capacity of the wind farm was determined based on the historical wind information from 1998 to 2008 [45]. Table 1 lists the details of the case study project in terms of the initial investment.

4.2. Application of the decision-making model

4.2.1. Climate change impact analysis

This case study attempts to explain to the decision maker how to consider the uncertainties associated with climate change and maximize the profit of the case project. The wind power production will be influenced by future wind speeds during the operation period of 20 years. The wind power production was estimated using the wind speed data extracted from RCP scenarios. The Korea Meteorological Administration (KMA) reported that the annual average wind speed on the Korean Peninsula is affected by the distance from the shoreline and that wind speeds are relatively stronger in the coastal zone than on land under RCP scenarios [48]. The National Institute of Meteorological Sciences (NIMS) of South Korea provides annual 80 m-high wind speed information for the Saemangeum wind farm project area based on the RCP8.5 and RCP2.6 scenarios for an operation period from 2019 to 2038 (Fig. 6) [45]. The change in annual average wind speed over 20 years ranges from 5 to 6 m/s, which will alter the economic feasibility of the case project.

4.2.2. Energy production estimation

The changes in the amount of wind power produced because of the changes in wind speed can be estimated using Eq. (1). Considering that the amount of wind power production is proportional to the cube of the wind speed, future power generation can be calculated using Eq. (4):

$$P_i = P_o \times \left(\frac{V_i}{V_0}\right)^3, \tag{4}$$

where P_i is the energy production in year i, P_0 is the energy production estimated based on historical wind speed data, v_0 is the average annual wind speed between 1998 and 2008, and v_i is the average annual wind speed in year i according to the RCP scenarios. Fig. 7 shows the energy production calculated using Eq. (4) under scenarios RCP8.5 and RCP2.6.

4.2.3. Estimated market factors of the case study

An economic assessment of the wind power project requires consideration of market factors, including the risk-adjusted discount rate, risk-free rate, exchange rate, inflation rate, maintenance cost, electricity sale price, and government subsidies. These data affect the cash flows of the project and can be estimated using historical data. In South Korea, the electricity sale prices of renewable energy providers are determined as the sum of the system marginal price (SMP) and renewable energy certificate (REC) price. The SMP is the market price at which Korea Power Exchange (KPX) purchases electricity based on the principle of supply and demand. Under the Renewable Portfolio Standard (RPS) regulation, which is a quota system for renewable energy supply, a non-renewable energy company should produce a certain amount of renewable energy. If the non-renewable energy company fails to satisfy the quota, it must purchase an REC from renewable energy providers. REC, which was introduced in 2012 in South Korea, is traded on the KPX and is priced according to the type and capacity of renewable energy.

The electricity sale price was estimated for the case study using SMP data from April 2001 to December 2016 and REC data from January 2015 to December 2016 [49]. The electricity sale price was estimated to be US$ 0.243 per kilowatt hour (KWh) with an exchange rate of US$ 1 to KRW 1100. The risk-adjusted discount rate, risk-free rate, and inflation rate were assumed to be 10%, 4%, and 3% per year, respectively. The O&M cost was assumed to be US$ 30 per megawatt (MW) based on the information presented by the IPCC [9]. Table 2 lists the estimated market factors of the case study.

4.2.4. ROA of the case study

Assuming each climate change scenario (RCP8.5 and RCP2.6) occurs, the cash flows that represent the investment, revenue, and O&M

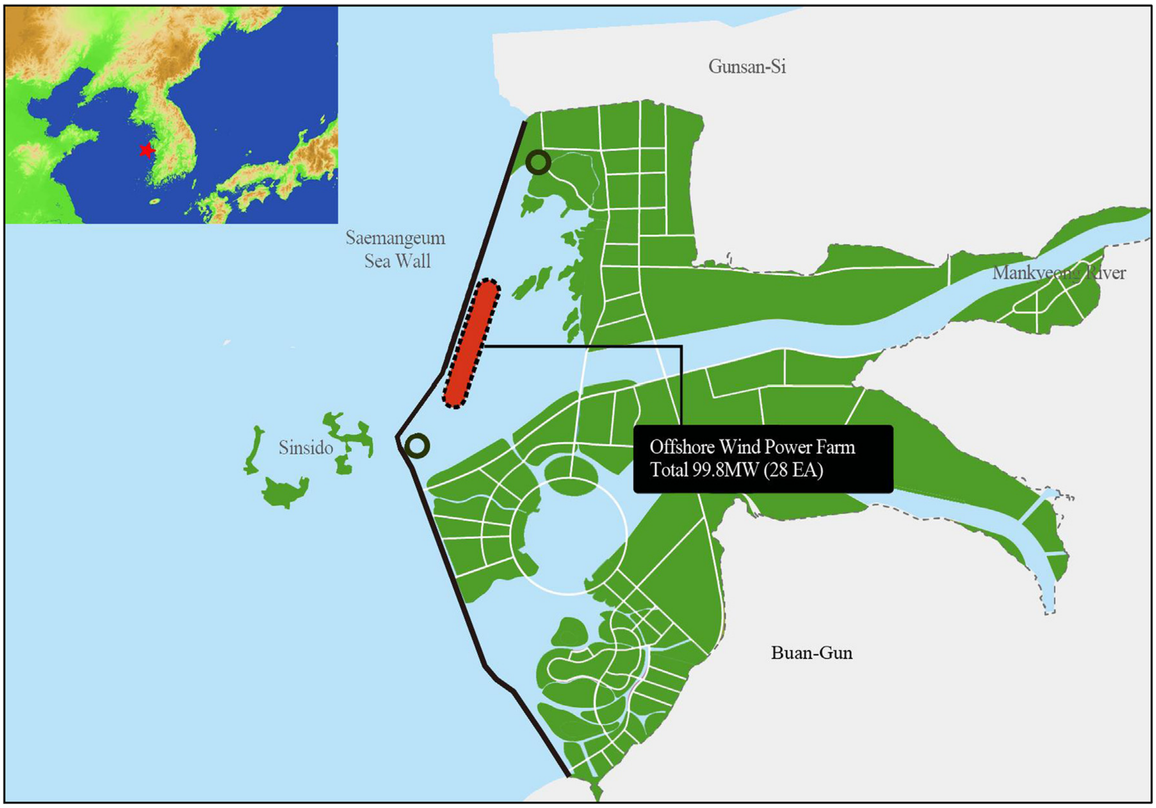

Fig. 5. Location of the Saemangeum offshore wind farm project.

Table 1
Details of the case study project [44,46,47].

Items	Values
Installed generator capacity	99.2 MW
Total investment cost	US$ 400 million
Wind power system	3.5 MW (24EA) and 3.0–3.2 MW (4EA)
Operational data of the wind power system	Rotor diameter: 134 m Tower height: 90 m Power generation efficiency: 26%
Construction period	2 years (2017–2018)
Operation period	20 Years (2019–2039)
Observed annual average wind speed at 80 m height (between 1998 and 2008)	5.78 m/s
Estimated annual wind power production	225,937 MWh

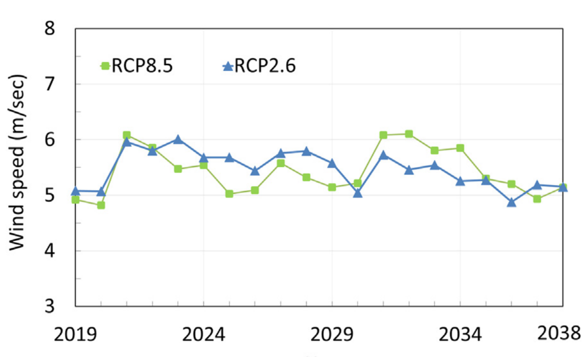

Fig. 6. Annual average wind speed at the project site at a height of 80 m between 2019 and 2038.

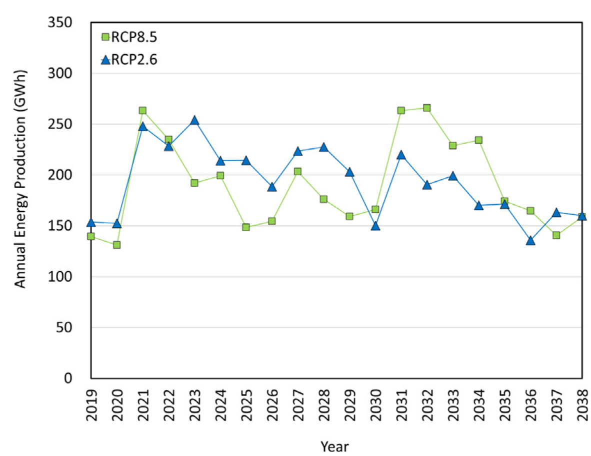

Fig. 7. Average annual wind power production between 2019 and 2038 under RCP8.5 and RCP2.6.

Table 2
Estimated market factors of the case study.

Parameter	Value
Risk-free rate	4% per year
Inflation rate	3% per year
Risk-adjusted discount rate	10% per year
O&M cost	US$ 30 per MWh
Wind power electricity selling price	US$ 0.243 per KWh

costs over the 20-year period of the project are shown in Fig. 8. The NPVs of the climate scenarios RCP 8.5 and RCP 2.6 are US$ − 104 million and US$ − 86 million, respectively. The projects are not economically feasible because the NPVs are negative. However, if the decision makers have options to expand 10 years after 2017, they can

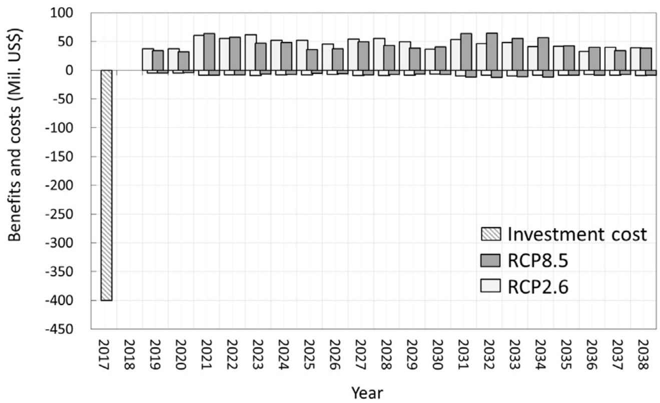

Fig. 8. Cash flows of the case study project under RCP2.6 and RCP8.5.

decide whether to expand, retain the existing facilities, or sell the facilities if profits deteriorate. Three expansion options were considered: expansion of facility scale by 100% (case 1), 200% (case 2), and 300% (case 3). The investment costs for the three cases are US$ 522 million, US$ 1044 million, and US$ 1566 million, respectively. For example, if climate conditions are favorable for the project, US$ 522 million will be invested in 2026 and the facility will be doubled to 198.4 MW (case 1). After facility expansion, the revenue will double. In contrast, if the expected return is not generated, the asset can be sold for US$ 200 million in 2026. Furthermore, if the project does not generate sufficient revenue to warrant expansion, it would be better to exercise the option of retaining the initial facility. In brief, investors can decide in 2026 which option to exercise based on the newly obtained climate condition information.

For ROA, the cash-flow volatility under a climate change was calculated using Eq. (2). The volatilities for the RCP8.5 and RCP2.6 scenarios were 43.0% and 34.6%, respectively, indicating that fluctuation in wind power production is wider under climate scenario RCP8.5 than under climate scenario RCP2.6. Figs. 9 and 10 show the binomial lattice calculations of RCP8.5 and RCP2.6, respectively. The underlying assets and option values are displayed for the period 2017–2026, during which the investor holds the right to exercise options, including abandonment (A), expansion (E), and continuation (C). Based on Eq. (3), the option values in 2017 under RCP8.5 and RCP2.6 were calculated to be US$ 330 million and US$ 209 million, respectively.

5. Results and discussion

Figs. 9 and 10 show that the investor can make investment decisions at each node in the binomial lattice using ROA. The NPV and OV were US$ −104 million and US$ 330 million, respectively, under RCP8.5. Because the NPV is negative, there should be no investment in the project. However, if the investor holds options, the feasibility of the investment is positive, as shown in the result of the case study. In other words, if the investor invests US$ 400 million in 2017, the expected revenue (option value) is US$ 330 million under the RCP8.5 scenario. In the case of the RCP2.6 scenario, the NPV is expected to be US$ −86 million. However, if the option is retained, the expected return is US$ 209 million. Table 3 summarizes the volatilities, NPVs, and option values under each climate scenario. The option value of RCP8.5 is larger than that of RCP2.6, which indicates that the larger volatility of

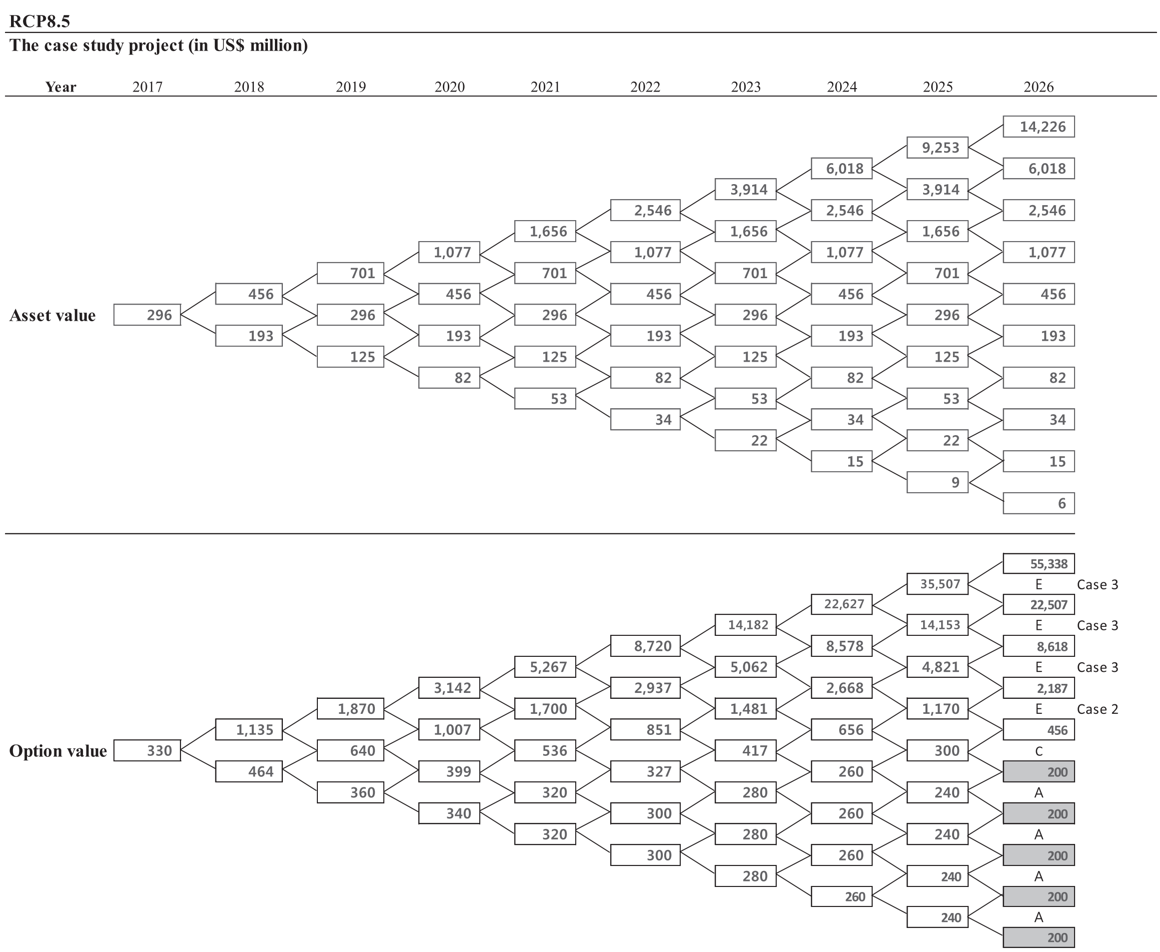

Fig. 9. Binomial lattice under RCP8.5.

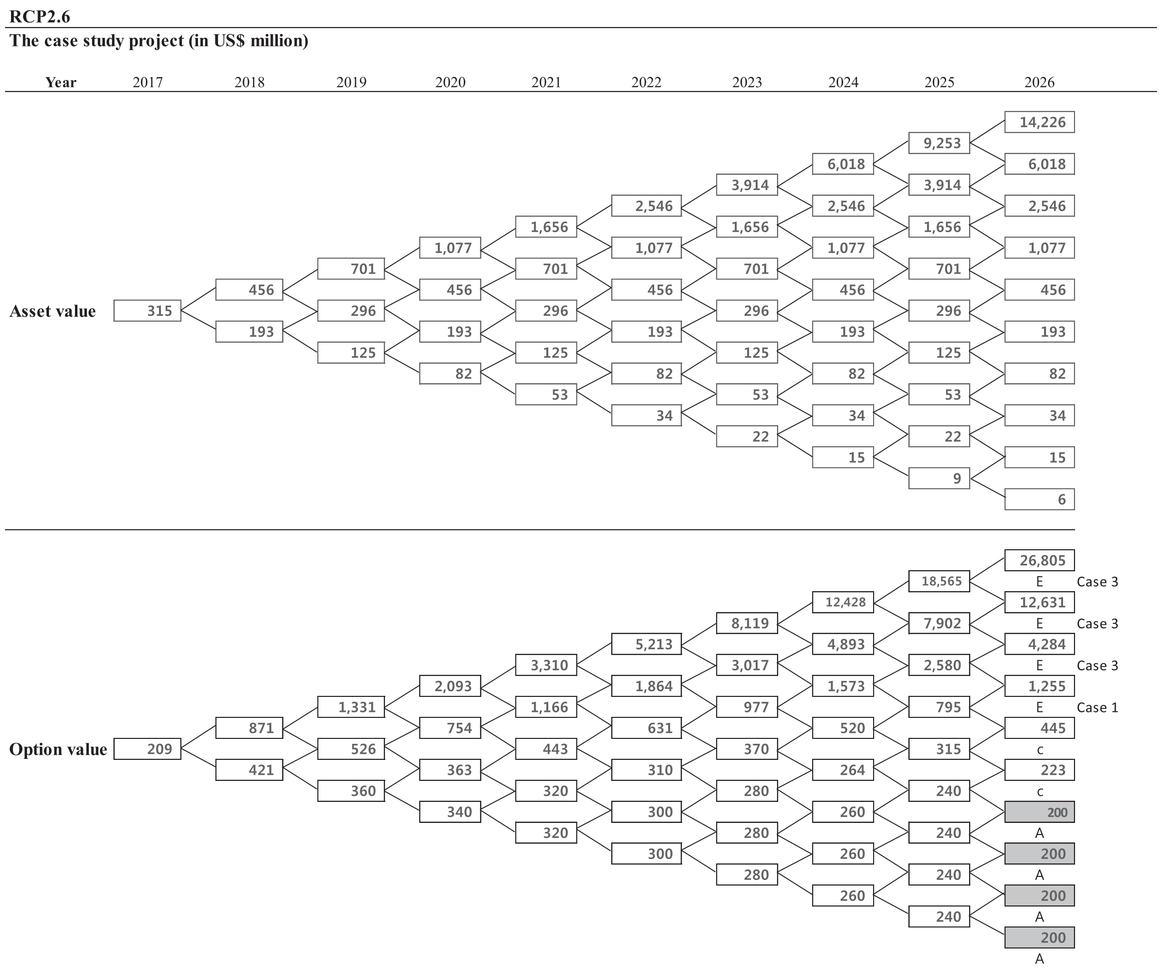

Fig. 10. Binomial lattice under RCP2.6.

Table 3
Results of ROA under RCP scenarios (in US$ million).

Result	RCP8.5	RCP2.6
Volatility	43.0%	34.6%
NPV	− 104	− 86
Option value	330	209

RCP 8.5 shows a more effective response to the application of the option compared to that under RCP2.6.

The case study shows that investors should use climate change scenarios to conduct more accurate economic analyses of offshore wind farm projects. The wind speed significantly changes in the case study area under the RCP scenarios. The proposed decision-making model using RCP scenarios suggests how to exercise options. The results of the case study demonstrate that investment in an offshore wind farm with options can increase its economic feasibility in response to climate change. Understanding the impacts of future climate changes could guide investment decisions in offshore wind farms.

Renewable energy, such as wind power, has been a big issue in South Korea. As a country with a large nuclear power capacity, the transition to a country with more environmentally friendly energy sources has been considered ideal but difficult. South Korea has been in need of clear proof that renewable energy sources are reliable in terms of economic feasibility. In this context, the results of this study are quite meaningful. This study provides the evidence that offshore wind power is economically feasible based on the results of ROA. Moreover, South Korea is one of the countries experiencing a high level of climate change. The consideration of climate impacts herein can further steer South Korea toward offshore wind farms. The results of the case study will help policymakers to develop appropriate investment strategies for wind power generation.

6. Conclusions

This study proposed a decision-making model using ROA to assess the economic feasibility of offshore wind power projects. The proposed model comprised two main functions. First, the impacts of climate change on wind farms can be quantitatively analyzed by estimating the volatility in potential energy production over the operation period. Volatilities were estimated from the future cash flows of the project under the RCP8.5 and RCP2.6 climate scenarios. Second, ROA can help investors formulate business strategies bolstered by options for improving the economic feasibility of offshore wind farms. The binomial lattice of the case study illustrated the option values for each node representing different times and different business environments. The model produced numerical results that can assist investors in making decisions (i.e., directing investors when to hold the options to expand, continue, or abandon the project). The case study involving an offshore wind farm in South Korea demonstrated that the value of the project changed from US$ − 104 million to US$ 330 million under RCP8.5 and from US$ − 86 million to US$ 209 million under RCP2.6. The case study proved that the holding options could effectively reduce risks and improve economic feasibility.

To the best of the authors' knowledge, this study is the first attempt at applying ROA to offshore wind farm projects using climate scenarios.

This study presented a clear methodology to incorporate the climate scenarios into the ROA of wind farms in order to minimize the impacts of climate uncertainty. Moreover, the expansion options of ROA were suggested in the proposed model considering the intrinsic nature of offshore wind farms: economies of scale. The proposed model can serve as a practical tool to assist decision makers in formulating investment strategies for estimating the economic feasibility of offshore wind farms under volatile climate conditions. The proposed model was only validated for offshore wind farm projects. In future research, the model must be improved and validated from the viewpoint of its application to onshore wind power facilities considering climate change.

Acknowledgments

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References

[1] Cavallo A. Controllable and affordable utility-scale electricity from intermittent wind resources and compressed air energy storage (CAES). Energy 2007;32:120–7.
[2] Murthy KSR, Rahi OP. A comprehensive review of wind resource assessment. Renew Sustain Energy Rev 2017;72:1320–42.
[3] Loncar D, Milovanovic I, Rakic B, Radjenovic T. Compound real options valuation of renewable energy projects: the case of a wind farm in Serbia. Renew Sustain Energy Rev 2017;75:354–67.
[4] Renewables 2016 global status report. Paris, France: REN21 Secretariat; 2016. p. 271.
[5] X-g Zhao, L-z Ren. Focus on the development of offshore wind power in China: has the golden period come? Renew Energy 2015;81:644–57.
[6] Kim K, Park H, Kim H. Real options analysis for renewable energy investment decisions in developing countries. Renew Sustain Energy Rev 2017;75:918–26.
[7] Kim K, Ha S, Kim H. Using real options for urban infrastructure adaptation under climate change. J Clean Prod 2017;143:40–50.
[8] Teotónio C, Fortes P, Roebeling P, Rodriguez M, Robaina-Alves M. Assessing the impacts of climate change on hydropower generation and the power sector in Portugal: a partial equilibrium approach. Renew Sustain Energy Rev 2017;74:788–99.
[9] Renewable energy sources and climate change mitigation: special report of the intergovernmental panel on climate change. Cambridge, United Kingdom and New York, NY: Intergovernmental Panel on Climate Change (IPCC); 2011.
[10] Davy R, Gnatiuk N, Pettersson L, Bobylev L. Climate change impacts on wind energy potential in the European domain with a focus on the black Sea. Renew Sustain Energy Rev 2017.
[11] Koletsis I, Kotroni V, Lagouvardos K, Soukissian T. Assessment of offshore wind speed and power potential over the Mediterranean and the Black Seas under future climate changes. Renew Sustain Energy Rev 2016;60:234–45.
[12] Satir M, Murphy F, McDonnell K. Feasibility study of an offshore wind farm in the Aegean Sea, Turkey. Renew Sustain Energy Rev 2017.
[13] Barroso MM, Iniesta JB. A valuation of wind power projects in Germany using real regulatory options. Energy 2014;77:422–33.
[14] Pryor SC, Barthelmie RJ. Climate change impacts on wind energy: a review. Renew Sustain Energy Rev 2010;14:430–7.
[15] Shoaib M, Siddiqui I, Amir YM, Rehman SU. Evaluation of wind power potential in Baburband (Pakistan) using Weibull distribution function. Renew Sustain Energy Rev 2017;70:1343–51.
[16] Ruffato-Ferreira V, da Costa Barreto R, Oscar Júnior A, Silva WL, de Berrêdo Viana D, do Nascimento JAS, et al. A foundation for the strategic long-term planning of the renewable energy sector in Brazil: hydroelectricity and wind energy in the face of climate change scenarios. Renew Sustain Energy Rev 2017;72:1124–37.
[17] Ramadan HS. Wind energy farm sizing and resource assessment for optimal energy yield in Sinai Peninsula, Egypt. J Clean Prod 2017;161:1283–93.
[18] Kim K, Jeong H, Ha S, Bang S, Bae D-H, Kim H. Investment timing decisions in hydropower adaptation projects using climate scenarios: a case study of South Korea. J Clean Prod 2017;142:1827–36.
[19] Kim K, Kim S, Kim H. Real options analysis for photovoltaic project under climate uncertainty. IOP Conf Ser Earth Environ Sci 2016;40. (012080).
[20] Kim K, Park T, Bang S, Kim H. Real options-based framework for hydropower plant adaptation to climate change. J Manag Eng 2017;33:04016049.
[21] Martinez-Cesena EA, Mutale J. Wind power projects planning considering real options for the wind resource assessment. Sustain Energy 2012;3:158–66. (IEEE Trans on).
[22] Kim B, Lim H, Kim H, Hong T. Determining the value of governmental subsidies for the installation of clean energy systems using real options. J Constr Eng Manag 2011;138:422–30.
[23] Čulík M. Real options valuation with changing volatility. Perspect Sci 2016;7:10–8.
[24] Jeong J, Ji C, Hong T, Park HS. Model for evaluating the financial viability of the BOT project for highway service areas in South Korea. J Manag Eng 2016;32:04015036.
[25] Abadie LM, Chamorro JM. Valuation of wind energy projects: a real options approach. Energies 2014;7:3218–55.
[26] Lee S-C. Using real option analysis for highly uncertain technology investments: the case of wind energy technology. Renew Sustain Energy Rev 2011;15:4443–50.
[27] Reuter WH, Fuss S, Szolgayová J, Obersteiner M. Investment in wind power and pumped storage in a real options model. Renew Sustain Energy Rev 2012;16:2242–8.
[28] Kim K-T, Lee D-J, Park S-J. Evaluation of R&D investments in wind power in Korea using real option. Renew Sustain Energy Rev 2014;40:335–47.
[29] Venetsanos K, Angelopoulou P, Tsoutsos T. Renewable energy sources project appraisal under uncertainty: the case of wind energy exploitation within a changing energy market environment. Energy Policy 2002;30:293–307.
[30] Yang M, Nguyen F, De T'Serclaes P, Buchner B. Wind farm investment risks under uncertain CDM benefit in China. Energy Policy 2010;38:1436–47.
[31] Boomsma TK, Meade N, Fleten S-E. Renewable energy investments under different support schemes: a real options approach. Eur J Oper Res 2012;220:225–37.
[32] Kitzing L, Juul N, Drud M, Boomsma TK. A real options approach to analyse wind energy investments under different support schemes. Appl Energy 2017;188:83–96.
[33] Kim K. Review of real options analysis for renewable energy projects. Korean J Constr Eng Manag 2017;18:91–8.
[34] Trigeorgis L. Real options and interactions with financial flexibility. Financ Manag 1993;22:202–24.
[35] Climate change 2014: synthesis Report. Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC); 2014.
[36] Qiu Y, Anadon LD. The price of wind power in China during its expansion: technology adoption, learning-by-doing, economies of scale, and manufacturing localization. Energy Econ 2012;34:772–85.
[37] Mun J. Real options analysis: tools and techniques for valuing strategic investments and decisions. 2nd ed Hoboken, New Jersey: John Wiley & Sons; 2002.
[38] Copeland TE, Antikarov V. Real options: a practitioner's guide. 2nd ed New York, New York: Cengage Learning; 2003.
[39] Kodukula P, Papudesu C. Project valuation using real options: a practitioner's guide. Fort Lauderdale, Florida: J. Ross Publishing; 2006.
[40] Jang K. domestic and overseas energy market outlook. Seoul, Korea: POSCO Research Institute; 2017. p. 2017.
[41] AGENCY KE. New & renewable energy statistics 2015. Yongin-si, Korea: KOREA ENERGY AGENCY; 2016.
[42] Park H, Kim K, Kim Y-W, Kim H. Stakeholder management in long-term complex megaconstruction projects: the saemangeum project. J Manag Eng 2017;33:05017002.
[43] Saemangeum development and investment agency. About Saemangeum. 〈http://www.saemangeum.go.kr/sda/en/sub/why/SMA20001.do〉; 2017 [Accessed Sep. 2017].
[44] Ko H. SDaI Agency, editor. Launching Korea's largest offshore wind power project at Saemangeum. Sejong-si, Korea: Saemangeum Development and Investment Agency; 2017.
[45] National Institute of Meteorological Sciences. Wind Velocity Maps using RCP Climate Scenarios. 〈http://www.greenmap.go.kr/06_future/timeSeries_yearList.do?Gubun=u#3#2#2〉; 2017 [Accessed Sep.2017].
[46] Song M. Establishment of Saemangeum 98 MW offshore wind farm. Today energy. Seoul, Korea: Today Energy; 2016.
[47] Doosan. Doosan wind power solutions. 〈http://www.doosanheavy.com/download/pdf/products/energy/en_wind_turbine.pdf〉; 2017 [Accessed Sep.2017].
[48] Climate change forecast for the Korean peninsula. Seoul, South Korea: Korea Meteorological Administration (KMA); 2013.
[49] KPX. December. REC transaction trend report. Seoul, Korea: Korea Power Exchange; 2016. p. 2017.